Telecom Australia

Telecom Information Kit No. 1.

FROM DOTS TO DATA

The Story of Digital Transmission and Data Communication.

1. Morse and his Code.

In 1844, an American called Samuel Finley Breese Morse sent the first message over a telegraph line between Baltimore and Washington in the United States, using a signalling code of his own invention. The message read "What hath God wrought?".

There had been other telegraph systems before Morse; in particular the Englishman Charles Wheatstone had developed a system using the deflections of a needle which was used in railway signalling. Both Wheatstone and Morse were indebted for their basic ideas to the American, Joseph Henry, who however did not patent his inventions.

But what made Morse's system different, and what caused it to be the telegraph system universally employed, were two factors; firstly, Morse's ability to lobby the United States Congress and convince them to pay for the construction of the first commercial telegraph line; and secondly, the simplicity and ease of the "Morse Code". Skilled operators could eventually send messages in the code at up to thirty words a minute.

Morse's basic telegraph system was extremely simple: the operator opened or closed a switch (known as the "key") to send electricity from a battery along the telegraph wire: the return path for the current was through the ground. At the receiving end, the pulses of current operated a pen which marked a strip of paper (later known as "ticker-tape") whenever current was present. Later, skilled operators found they could spell out the message just listening to the sound that the pen made; and eventually the marker was replaced by a mechanism to amplify the sound.

The problem was how to use these pulses of electrical current to represent the letters of the alphabet and to spell out a message.

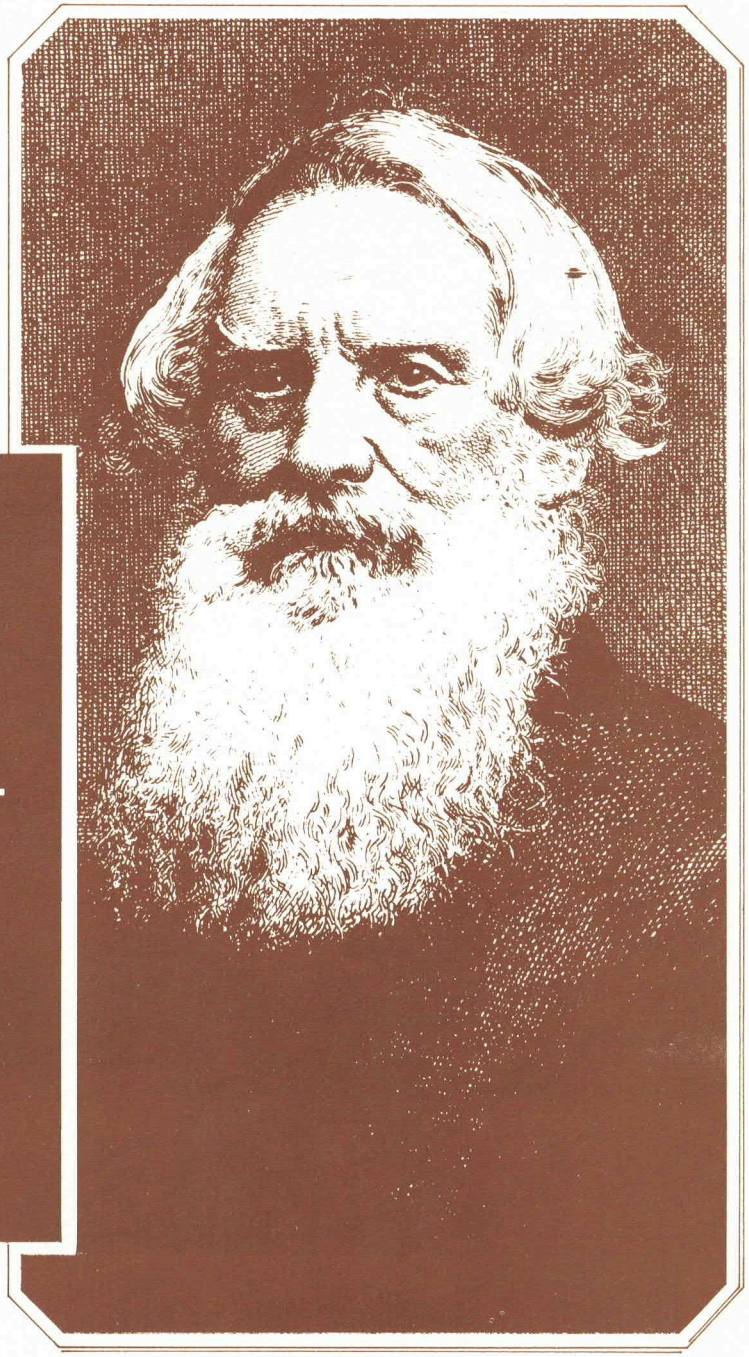
MORSE CODE

A ·–	J ·–––	S ···
B –···	K –·–	T –
C –·–·	L ·–··	U ··–
D –··	M ––	V ···–
E ·	N –·	W ·––
F ··–·	O –––	X –··–
G ––·	P ·––·	Y –·––
H ····	Q ––·–	Z ––··
I ··	R ·–·	

1 ·–––––	6 –····
2 ··–––	7 ––···
3 ···––	8 –––··
4 ····–	9 ––––·
5 ·····	0 –––––

. (Full stop) ·–·–·–

, (Comma) ––··––



Samuel Finley Breese Morse

Morse decided that the best way was to use two different kinds of electrical pulse: one short and one long; a dot and a dash. By combining these two kinds of pulses, it was possible to represent every letter in the alphabet by a code of four pulses or less.

He made a careful study of the frequencies of different letters of the alphabet used in printing, by examining the numbers of each letter kept in typesetters' print trays. He then gave the letters which were most frequent the shortest codes. In this way, the number of pulses that had to be sent to communicate an average sentence in English could be kept to the minimum.

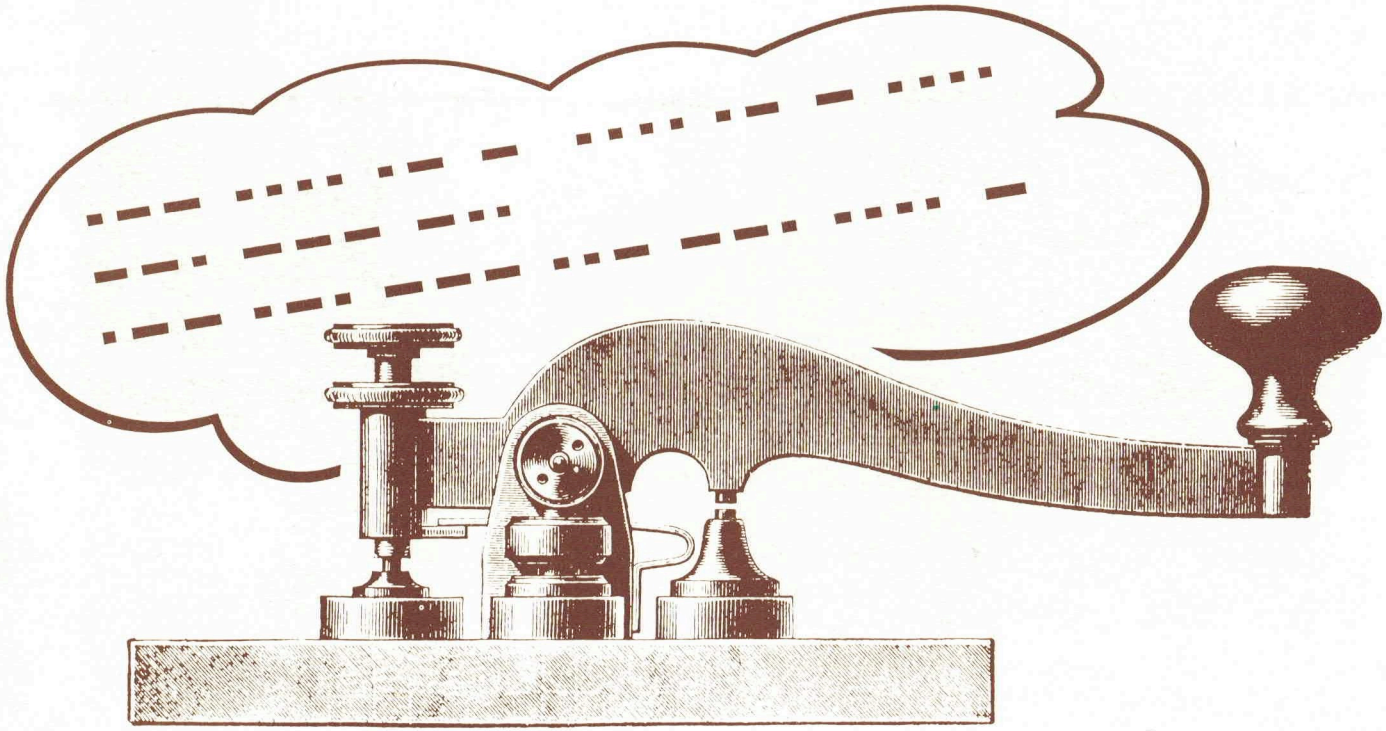
Thus the letter "E", which is the most commonly used in English, was given a Morse code of a single dot. The next most common letter, "T", was represented by a single dash. Less common letters were combinations of dots and dashes. Numerals and punctuation marks were made up of combinations of five and six pulses respectively.

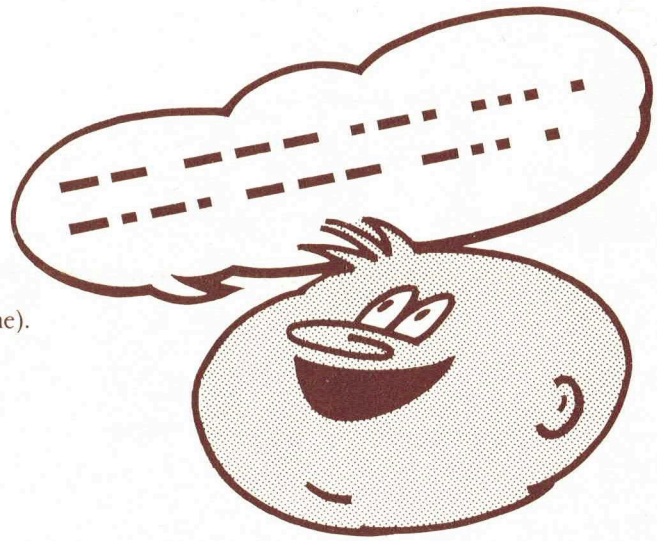
There was a strict set of rules governing how to send messages in Morse Code. A dash was to last as long as three dots. A space as long as one dot was left between the pulses making up the same letter. A space as long as one dash was left between different letters, and a space as long as five dots was left between different words.

Although all this starts to sound very complicated, in practice the operators soon found they could send and receive the messages with increasing speed and reliability. In a very short time, Morse's telegraph system became adopted in almost every industrial country in the world.

The first telegraph line to be erected in Australia was in 1854, between Melbourne and Sandridge (now Port Melbourne). Other lines in other colonies quickly followed. Adelaide, Melbourne and Sydney were joined by telegraph in 1858. In 1859, a submarine cable was laid from Victoria to Tasmania. Brisbane was connected with Sydney in 1861, and Queensland began to push its lines rapidly northward. Perth, beyond the barrier of the Nullarbor Plain, took rather longer to be connected with the other colonies, until 1877.

In 1872, the colony of South Australia pushed a line through the very centre of Australia to Darwin in order to connect with a submarine cable from Java which then connected with the now extensive telegraph systems of Europe, and so putting Australia in telegraph contact with England and the rest of the world.





Much later, around the turn of the century, when the Italian inventor, Gugliemo Marconi was developing radio (or "wireless telegraphy" as it was then called), Morse Code was still used to send messages using the new communications method. This was largely because of the simplicity of the method of transmission compared with other methods, and particularly compared with the problems of transmitting the human voice.

So on a wintry December day in 1901 in Newfoundland, it was a letter of the Morse alphabet–the three dots of the letter "S"–that Marconi heard in his earphone, a signal transmitted against all the predictions of the experts across the Atlantic Ocean from England. It was a very faint signal, but Marconi could pick it out against all the background noise.

It is this recognisability of Morse signals in situations of high noise and low transmitting power that has ensured the continuing use of Morse's code in such situations right up to the present day.

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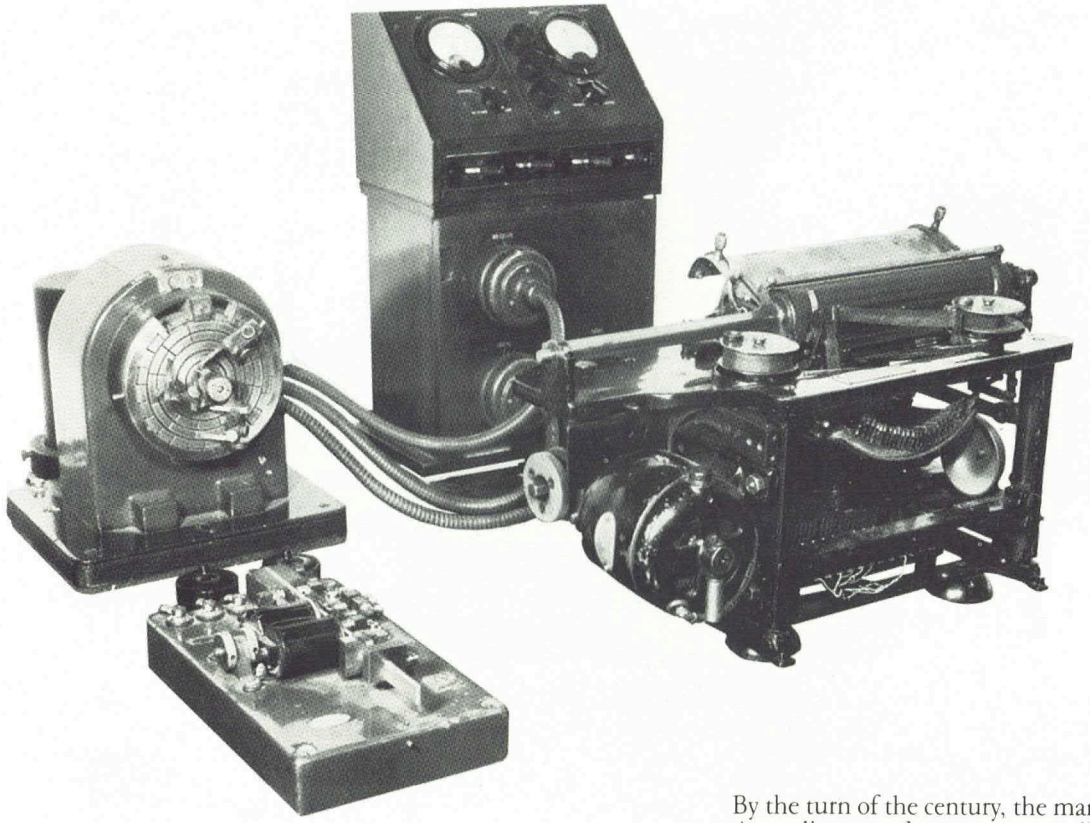


Murray multiplexer receiving terminal with one channel equipped with a Morkrum Page Printer.

2. From Telegraph to Telex.

By the turn of the century, the manual Morse system in Australia covered some 20,000 miles. With trunk telephony still on the horizon, and interstate trunk calls still 20 years in the future, the demand for telegraph transmission was increasing rapidly. An operator was only capable of transmitting an average of 30 words per minute. To fully utilize the carrying capacity of these single wire earth return circuits, a speedier system was needed.

About 1900, Wheatstone invented an automatic Morse transmitter which could transmit up to 400 w.p.m. on a good line. Operators at keyboard paper tape punching machines prepared tapes which were punched in Morse Code and converted to electric pulses by the transmitter or reader. At the receiving end, an improved high speed inking register was installed on the line. The tapes, marked in Morse Code, were then handed to operators to decode. Driven by weights or battery powered DC electric motors, this system was in use in the Australian telegraph service for many years.

As telegraph traffic increased, engineers looked for other means to increase the message carrying capacity of the telegraph lines. Many methods were proposed, but only the more worthy survived. A French inventor, Baudot, contrived a character code better suited to automatic operation, consisting of five units. This new code enabled the manufacture of page printer telegraph machines which resembled the typewriter, and reduced the amount of training required for the operator–but increased the complexity for the telegraph mechanic.

Methods were also developed which enabled 'multiplexing' –sending more than one message along the same line at the same time. Two, three or four channels could be combined by transmitting the code for one character from the first channel, then one from the second, and so on. At the receiving end, these signals were sorted out in correct sequence by equipment in exact synchronism with the sending equipment.

Such methods were used on heavy traffic telegraphic lines in Australia until the early 1950's.

The increase in telegram traffic between post offices and the growth in private line telegraph services between business houses, generated a demand for a page printing telegraph machine which could be operated without knowledge of special codes and procedures. The Teletype Model 12 System used a Morkrum Printer as a receiver in an early attempt to build a direct printing, keyboard operated, page printing system. By late 1920 more sophisticated versions from Teletype and Creed Companies became so well known that these trade names have passed into the language. The general name for this kind of equipment is the 'teleprinter'.

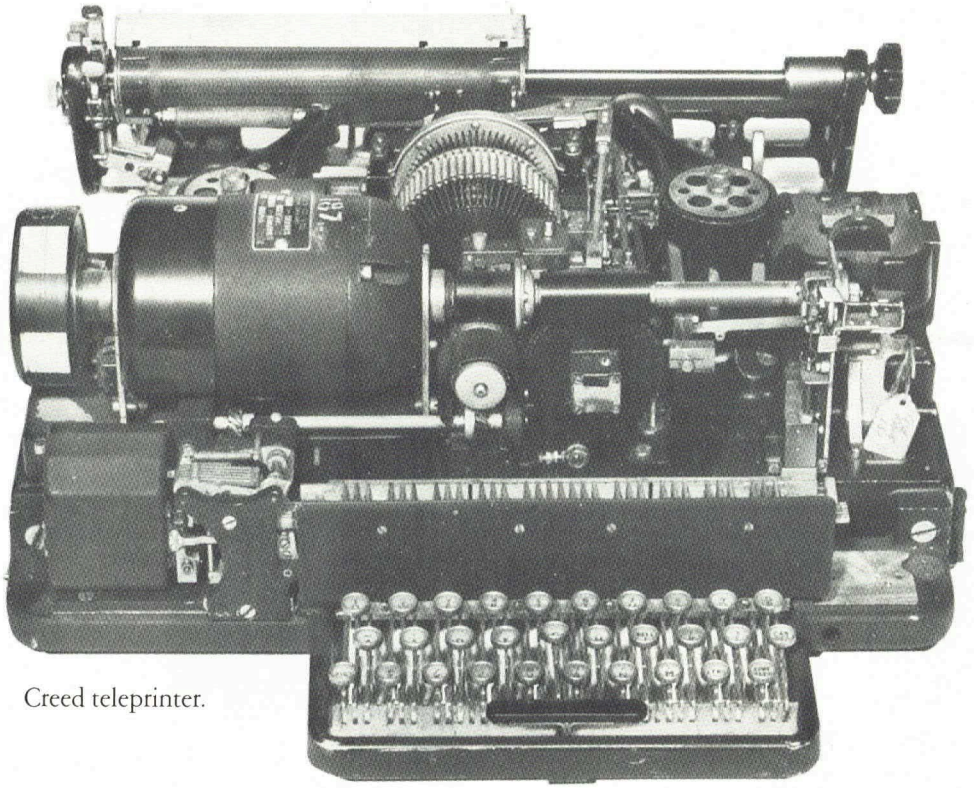
By the 1950s the Teleprinter was the main telegraph terminal device in use. There was then a growing need for post offices to be able to communicate direct with each other, in order to handle the growing telegram traffic. To this end, the Australian Post Office instituted a message switching system called the Teleprinter Reperforator Exchange Switching System (TRESS) in 1959. By this system a series of automatic switching centres directs each message to its destination for printing out on the receiving teleprinter.

To send a telegram by TRESS, an operator types out the correct address code at the start of the message on the teleprinter, and completes the telegram. At the switching centre, equipment recognises the address, stores the message and transmits the telegram to the receiving teleprinter when the line is free.

The Creed model teleprinter, based on a printing telegraph developed by the Creed brothers in England early this century, can transmit approximately 66 w.p.m. which compares with an experienced typist's average speed of 50 w.p.m.

Morse code had long been replaced on main line routes, but the nationwide introduction of TRESS over the next few years marked its disappearance entirely from country and suburban lines by the early 1960's.

There is a rapidly growing worldwide demand for the transmission of business and commercial messages with a written record. The business world recognised the usefulness of the telegraph printer for this purpose, and many point-to-point services were established. Telecommunications administrations throughout the world, and in this country, recognised the advantages of connecting telegraph machines together over a network of switching points and connecting paths, so they instituted a fully automated teleprinter exchange service called 'telex' in 1954.



Creed teleprinter.

The Australian telex network operates in a similar manner to the telephone service, with connection possible to telex subscribers anywhere in Australia or the world for 'talking in type'.

A telex subscriber merely types out the telex number or code for the called party, awaits an acknowledgement from the called machine and then transmits even if the called teleprinter is not staffed. The call can operate as a 'conversation', each subscriber being able to answer the other during the call.

Auxiliary to telegraphy are various machines for the facsimile reproduction of drawings, documents and photographs. In the past, the transmission of photographs by news agencies, and of meteorological information in the form of weather charts, has proved very successful but too expensive for general use.

Only recently has the idea of using facsimile transmission for ordinary business gained momentum, due largely to the development of cheaper equipment. All business facsimile machines work on the same basic principle. In each case a reader of some kind converts the optical information on a document into an electrical signal which is then transmitted down a telephone line to a receiver at the other end. The signal is essentially the same as that used to carry speech between conventional telephones. At the receiving end it is used to reproduce an exact copy of the original document by any of a number of copying techniques.

Growth in the general acceptance of facsimile transmission, however, is slow but during the next few years most business facsimile units are expected to be installed as part of a single, simple system linking perhaps only two locations and expanding in due course to corporation-wide networks, and eventually into national and international networks similar to today's telex networks.

Telegraph-type communication has been the forerunner of information transfer for well over a century and in its latest form, digital transmission, its life will extend well into the future.

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3. On Binary Numbers.

Modern electronic computers are capable of carrying out millions of mathematical calculations every second: adding, multiplying and juggling numbers at a speed hard for us to comprehend, let alone match. And they do this using what is to us rather a peculiar type of arithmetic, using what are called binary numbers. Indeed, within the computer, these numbers are represented not as familiar digits, but as states of electrical charge, or pulses of high or low voltage.

How can numbers be represented this way?

Consider that the number system that is familiar to us from our earliest school days is based on the number ten for the very good reason that we have ten fingers (including thumbs!). Primitive people counted on their fingers, and so the number ten assumed a particular importance. But the fact that we have ten fingers is just an accident of evolution: we could just as easily have ended up with eight fingers, or twelve; and we would then no doubt use a number system with eight or twelve as the base.

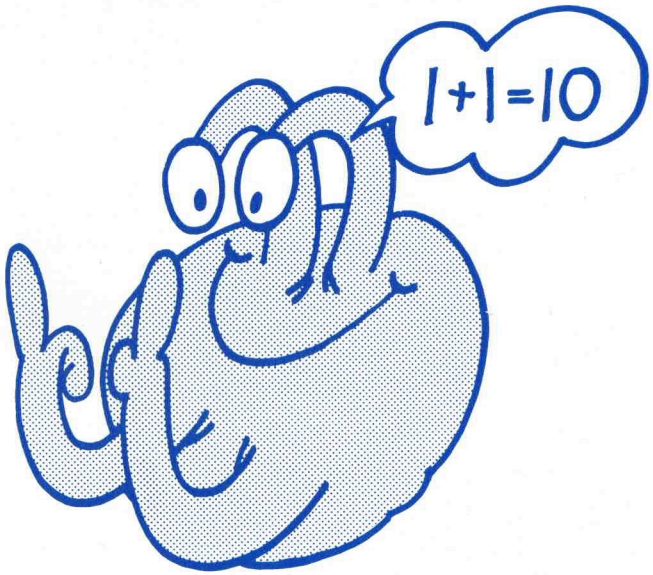
What does it mean to say that our number system is based on the number ten? Well, it means that we use just ten distinct symbols–the digits '0', '1', '2', '3', '4', '5', '6', '7', '8', and '9'–to enable us to write down combined symbols which represent any number at all. We do this using a system called 'positional notation', which means that the **value** of a particular digit depends on its position. Thus, when we write down a number like '564', the digit '5' represents, in this particular case, five hundred; the '6' represents sixty, and the '4' just four units. You may remember doing simple arithmetic when you were very young, with the numbers arranged in columns, like this:

HUNDREDs	TENs	UNITs
5	6	4

For every column to the left of the units column, we must multiply the digit in that column by another power of ten. A number like '564' represents a process or sum like this:

$$564 = 5 \times 10 \times 10 + 6 \times 10 + 4$$

This system of positional notation is by far the easiest we have been able to devise for representing numbers. It was developed by the Arabs in about 700-800 AD, based on work by the Hindu mathematicians of India.



But, as we have discussed, our use of the base ten is quite arbitrary. Other bases are quite possible, and some of them turn out to be more useful for certain purposes than the base ten. The simplest base we can imagine for a system of positional notation is the number two. This is the binary system used by computers.

In the binary system, just two symbols are used. Usually, these are written down as '0' or '1'–but it is very easy to confuse these with decimal numbers. As soon as we see the combined symbol '10', we automatically think 'ten', which is what it represents in the decimal system; but it can mean another number if the base is different. So to avoid that confusion, we will use special **bold** symbols for the time being to represent binary numbers.

So, in the binary system, we use the two special symbols **'0'** for zero and **'1'** for one. Imagine, if you like, that these are symbols invented by a strange race of two fingered beings who can only count up to two on their hands.

Using just two symbols, it is perfectly possible to represent any number that could be written down with our familiar decimal system. In the binary system, positional notation works just as it does in the decimal system, except that the columns to the left of the units column represent increasing powers of **two** instead of ten. Let's consider we have a number which might have been written down by our imaginary two-fingered beings, say **'101'.** Remember these bold symbols represent something different than in

the decimal system, so this number is **not** the same as 'one hundred and one'. To find out what number it really represents, we might write it down in columns like this:

FOURs	TWOs	UNITs
1	**0**	**1**

For every column to the left of the units column, we multiply the digit in that column by another power of **two.** Thus a number like **'101'** represents a sum like this:

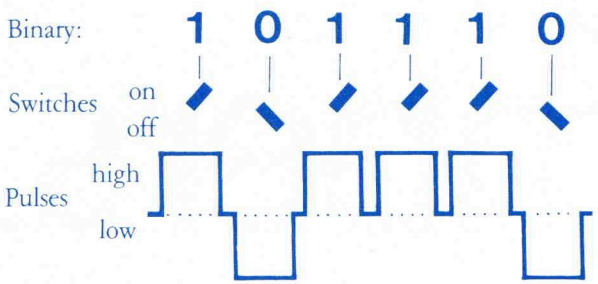
101 = **1** × two × two + **0** × two + **1** unit
= four + zero + one
= five (5 decimal)

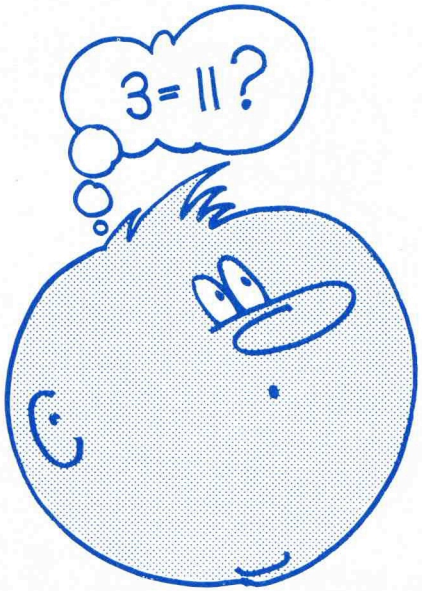
See the table on the right for some more binary arithmetic using the two special symbols.

The point to recognise is that any number can be represented in binary notation just as it can in our familiar decimal notation, and arithmetic can be carried out perfectly well in such a binary system.

The great advantage of binary numbers is that they can be represented so easily by electrical means because there are only two symbols involved. In a computer, for example, a row of switches with only two positions each–'on' or 'off'–can be used to represent binary numbers. Similarly, in transmitting information, a train of electrical pulses which are either 'high' or 'low' in voltage can also represent a binary number (see illustration below). This is far easier than trying to represent the ten distinct symbols of decimal notation, and consequently it enormously simplifies the design of computer circuitry, and provides a simple method of digital transmission.

Decimal number: 46 Binary equivalent: **101110**





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SOME BINARY ARITHMETIC

Number	Decimal Notation (Arabic symbols)	Binary Notation (Arbitrary symbols)
One	1	**1**
Two	2	**10**
Three	3	**11**
Four	4	**100**
Five	5	**101**
Six	6	**110**
Seven	7	**111**
Eight	8	**1000**
Nine	9	**1001**
Ten	10	**1010**
Eleven	11	**1011**
.....		
Thirty One	31	**11111**
Thirty Two	32	**100000**
.....		
Ninety nine	99	**1100011**
One hundred	100	**1100100**

Addition

1 + 0 = 1
1 + 1 = 10
1 + 10 = 11
10 + 10 = 100
10 + 11 = 101

```
 1101
  101 +
-----
10010
```

(Each time **1** and **1** are added in the same column, you must write down **0** and carry **1** into the next column left)

Multiplication

1 × 0 = 0
1 × 1 = 1
1 × 10 = 10
10 × 10 = 100
10 × 11 = 110

```
 1101
  101 ×
------
 1101
00000
110100
-------
1000001
```

(Multiplying any number by **10** is the same as moving it all one column further left and putting **0** in the units column)

4. Analogue and Digital- the Smooth and the Bitty.

We often hear the word 'digital' used these days. You are probably familiar with such phrases as 'digital clocks', 'digital computers'–perhaps even with 'digital records'. Rather less often, we hear a word that is loosely used as the opposite of digital–the word 'analogue'. You may have heard of 'analogue clocks' or 'analogue computers'.

What do these words mean in such phrases, and what is the difference between them?

We'll start by explaining the meaning of 'analogue' because although it is the less familiar word, in fact it describes something which seems rather commonplace.

The word 'analogue' is derived from 'analogous' which means 'similar or parallel to'. When we use an 'analogy', we are likening something to another thing which in some ways is similar to it. We might say, for example, that the human body is like a factory; it needs raw materials to be fed to it before it can act; wastes need to be disposed of; the brain acts like the factory manager, and so on. This would be an analogy, and we could then say that a factory is an **analogue** of the human body. A doll's house is an analogue of a real house.

What has all this to do with 'analogue clocks' and so on? Well, when we come to making a measurement of something, whether it be the amount of fuel in the tank of our car, the length of a bit of wood, or the time of day, there are two fundamentally different ways of representing the result–the analogue and the digital. An analogue method is one which in effect creates a little model of the thing we are measuring. For example, one method of representing the time of day is exemplified by a sundial. The movement of the shadow over the surface of the sundial is a model of the movement of the sun: it is an **analogue** of that movement. A sundial, in fact, is an analogue clock.

Usually, however, when we speak of an 'analogue clock', we are not thinking of a sundial, but of the kind of clock where the hands sweep around the clock face. The movement of the hour hand, in fact, is a kind of model of the movement of the sun. If it is a clock with a second hand, then you will be able to see that move as you watch, sweeping smoothly and continuously around the face: just as smoothly and continuously as the sun seems to move around the Earth, though of course very much more rapidly. At any moment, you can look at such a clock and get an instant measure of the exact time. If you look closely enough, you can even estimate the time to small parts of a second, as the hand moves between the marks on the face.

Now think of a modern 'digital clock'. The time is shown by a display of numbers, or digits. The word 'digit' originally meant only 'a finger or toe', but because we learnt to count on our fingers, the numbers themselves came to be called 'digits', too. But the display of numbers on a digital clock has no direct relationship with the movement of the sun through the sky. Instead, the numbers represent an arbitrary division of the day into 24 hours, each hour into 60 minutes, and so on. The time shown does not change continuously and smoothly, but in a series of jumps: with most digital clocks the right-hand number changes over at the end of each minute, having stayed the same during that time. It is impossible, with such a clock, to know the exact time **in between** changes in the last number of the display. You don't know what the time is between the jumps.

A digital measurement, then, is one that is represented by a limited group of numbers or digits: and because of this, it is characterised by changing only in a series of jumps. In a car, the speedometer is an analogue device; the distance meter (odometer) is a digital device.

Now, these two ways of representing a measurement have various advantages and disadvantages. One advantage of an analogue measurement is that we can look at it quickly and get a 'feel' for the approximate amount without worrying about the exact numbers involved: for example, when you look at a fuel gauge in a car, you don't want to know the exact number of litres in the tank, but just whether it is nearly empty or nearly full. So an analogue reading is ideal. At the same time, the accuracy of an analogue measurement can be very high, particularly with a quantity that is changing smoothly and rapidly: for example, you can estimate fractions of a second by looking closely at the movement of the second-hand on a clock face.

However, when it comes to communicating information about a measurement, we are almost always forced to do a mental conversion from analogue to digital. For example, if someone asks us the time, we might look at an analogue watch and see the position of the hands, but have to convert this information into a digital form, so that we can say, "It's 12:24" or whatever.

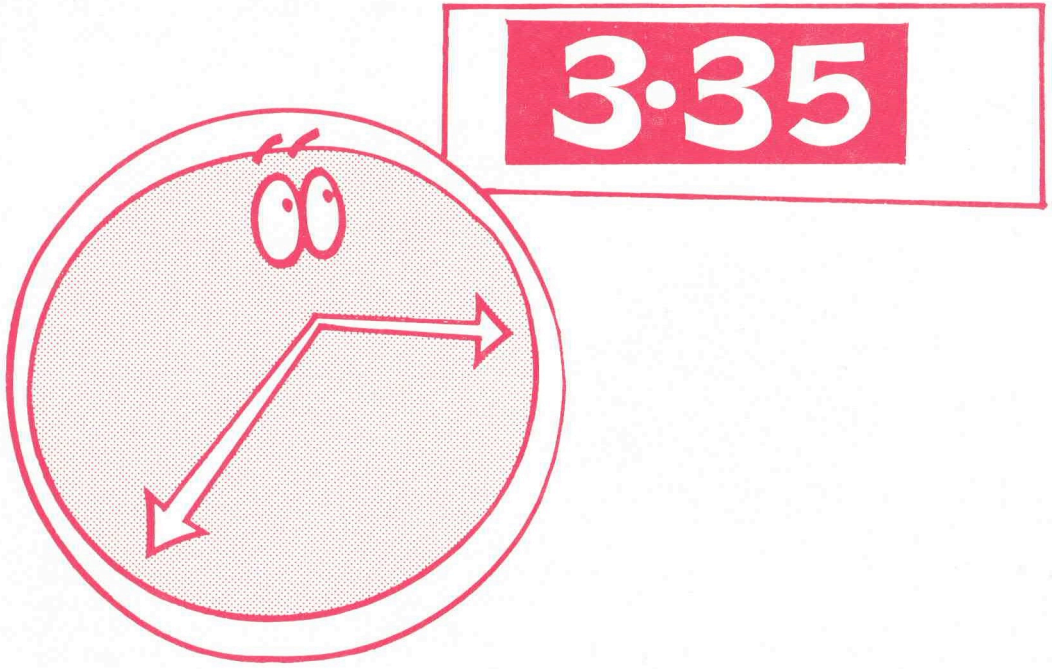
Another major advantage of digital representation is that it is much easier to do calculations with figures than it is with the positions of a clock hand, for example. If we are told that a train is due in 16 minutes, then it is much easier to add 16 to 12:24 in our heads and get 12:40 than it is to work out the angle the minute hand will turn through in that time. So when we are doing calculations, it is much easier to start with a digital measurement.

However, we have to bear in mind that in using digital methods some accuracy is always lost. As we discussed earlier, because digital measurements always change in jumps, we can never be sure of the exact measurement in between changes of the rightmost digit on the display. We can use more and more digits to get a more and more accurate answer–for example, our digital watch might display seconds or even tenths of a second–but we cannot use an infinite number of digits: the display has to stop somewhere. In practice, of course, we can use enough digits for the accuracy we require for our particular purpose.

Almost all computers in the world are digital computers, which represent information internally by means of numbers of a predetermined accuracy.* When using such computers, it is often important to take into account the loss of accuracy caused by using only a limited number of digits.

But despite the limitations on accuracy, digital methods are much more useful than analogue methods in many applications, and particularly in applications where information has to be transmitted from one point to another.

*(see separate sheet on "Binary Numbers")



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5. Sound into Pulses- the Benefits of Digital Transmission.

One of the main advantages of digital* technology is in the area of the transmission or communication of information from one point to another. In the sense we will use it here, information can be any value, measurement or signal we want to transfer. It can be, for example, the human voice or the sound of music.

Keen stereo listeners like to talk about 'hi-fi'–short for 'high fidelity'–by which they mean the reproduction of music while faithfully preserving its quality as much as possible. When you are sitting in front of a band or an orchestra, you are hearing the music directly, just as it comes from the instruments, in the highest fidelity possible. The problem faced by a record company is how to preserve this fidelity and re-create it in your living room when you play a record. Ideally, you should be able to sit back and close your eyes and hear the sound exactly as you would if the band was there in front of you.

In reality, there are a number of problems that prevent the achievement of this ideal: noise, distortion, loss of dynamic range and so on. For our discussion, we'll concentrate on the problem of noise.

Noise is any sound on the record that wasn't there at the performance during the recording session. More generally, it is any unwanted signal that adds on to the information being transmitted. When a record is being made, noise is introduced at every step of the recording process, although of course the company makes every effort to reduce such noise to as low a level as possible. The sound that reaches the microphones is converted into an electrical signal which is then recorded on a wide magnetic tape moving at high speed. This tape is then used to control the cutting of a master disc, from which moulds are then made. These in turn are used to mass-produce the records which are eventually sold in shops. Noise is produced at every step, not forgetting that introduced by your own stereo equipment. It can never be entirely eliminated.

*See separate sheet "Analogue and Digital" for the meaning of this word.

The same problems of noise are shared by any method of transmitting information, and certainly by telecommunications, including telephone calls.

Now until very recently, record companies have used purely analogue* means to transfer the information representing the sound of the music from one point to another. That is, they use an electrical signal which changes smoothly in strength, exactly modelling the smooth but complex changes in the sound.

When noise is created in the recording process–because of tape hiss, dust on the master disc, electrical interference or any other cause–this is added on as a random signal on top of the complex electrical signal. And there is no way that electronic equipment can tell such random noise from the original electrical signal. So there is no way it can be removed again.

We can see this more clearly if we draw a graph of the level of the analogue audio signal over a period of time (Diagram 1a). The shape of this graph represents both the changes in the original sound and the changes in the electrical signal that models it. Now if we add to this audio signal some random noise, this affects the shape of the signal, and this degrades the sound that your stereo reproduces (Diagram 1b).

The trouble with an analogue audio signal is that its **exact** shape has to be preserved if you are to hear the music exactly as it was when it was played. If there was a means of transmitting the signal so that only the **overall** shape of the signal mattered, then noise would not be so important.

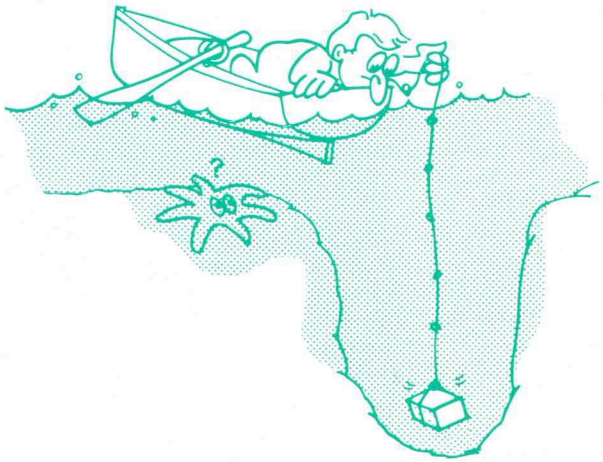
Such a method exists in digital encoding. One popular form of digital encoding is called pulse code modulation (PCM), for reasons we will discuss later. In this method, the original sound is monitored by electronic equipment and at very short intervals of time a **sample** is taken of the level of the audio signal at that moment. This information is then converted to a binary number** which is then transmitted as a series of on-or-off pulses.

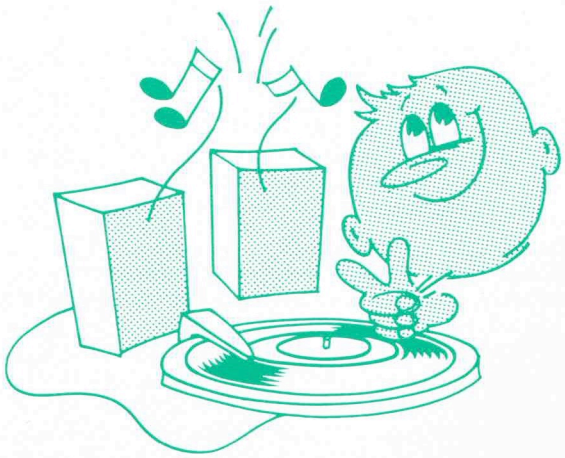
*see separate sheet "Analogue and Digital" for the meaning of this word.

To make this easier to understand, consider this analogy. Let's imagine that the port authorities wish to know the shape of the bottom of a harbour, so that ships can navigate more safely. It certainly isn't possible to drain the harbour and take a photograph of it, so what they do instead is send out a boat which travels slowly across the harbour. Every few metres, a man at the back of the boat drops down a plumb-line (a weight at the end of a rope), until it reaches the bottom of the harbour. The line has knots tied in it at regular spaces, and the man calls out the number of knots under water so indicating the depth of the harbour at that point. A clerk writes these down, and eventually it will be possible for him to draw a graph of the shape of the harbour by using these numbers.

The man in the boat has been taking samples of the depth of the harbour at frequent intervals. In just the same way, the electronic equipment used in pulse code modulation takes a sample of the level of the audio signal, and converts these measurements into numbers, or digits (see Diagram 2). It is important to note at this point that because the measurement is represented by a limited number of digits, there is some slight loss of accuracy (in our analogy, the depth of the harbour is indicated by whole numbers of knots under water, not by fractions or parts of the distance between knots).

**see separate sheet "On Binary Numbers".





These numbers are then coded into a series of on-or-off electrical pulses (in some systems they may be strictly high-or-low pulses), in very much the same way that letters of the English language were coded into the dots and dashes of Morse code. These pulses are then transmitted.

Now, although noise will still occur during this transfer of information, exactly as it does in analogue transmission, it has little effect unless the level of noise is very high. The reason for this is that now the receiving device only has to examine the incoming signal to determine if a pulse is present at a particular moment or not. The **exact** level of the signal is not important at all, so long as an 'on' condition can still be clearly distinguished from an 'off' condition. (see Diagram 3a and 3b). The original signal can then be reconstructed exactly (see Diagram 3c).

However, we must remember that the information transmitted by digital methods can only approximate the original analogue sound. There are two reasons for this. Firstly, as we have mentioned, the level of the audio signal can only be represented by a limited number of digits, thus restricting the accuracy with which it can be measured. Secondly, the original signal is only sampled at the end of discrete intervals of time, and we know nothing of what is happening to the signal between these intervals. For this reason, the sampling must take place at very short intervals indeed.

It turns out that the sampling must occur at least twice as often as the fastest changes in the audio signal. In technical terms, the frequency of the sampling must be at least twice that of the highest frequency in the audio signal to be transmitted. For 'hi-fi', this means the sampling must occur 50,000 times a second! This is possible with modern electronic methods, and in practice the errors owing to digital encoding can be reduced to a negligible amount, and the problem of noise is almost entirely eliminated.

Record companies are now introducing digital methods for at least the taping stage of the recording process. Of course, with an audio signal, these digital pulses must eventually be converted back to an analogue form, because this is how your ears work! But this is not too difficult. The quality of such 'digital recordings' exceeds that of more conventionally recorded records. Eventually, home stereo equipment may be able to reproduce discs which are entirely digital in manufacture. Such discs would not have the familiar wiggly spiral of today's records, but might have a series of tiny pits in their surface, scanned by lasers.

Pulse code modulation also has many benefits in the telephone system, where noise can substantially degrade the quality and understandability of telephone conversation. For voice transmission, the sampling rate need only be about 8000 times a second. Telecom Australia has already installed a number of digital transmission systems between exchanges. This means that it is possible that when you next make a phone call, your voice will be conveyed at least part of the way by a digital system, sampling the electrical signal which represents your voice, breaking it up into binary numbers, and transmitting it as a series of electrical pulses.

Apart from the benefits of reducing noise and cross-talk (the interference between two neighbouring telephone lines) pulse code modulation allows many more telephone conversations to be transmitted along the same set of wires.

This is possible using 'time division multiplexing'. Although this sounds rather formidable, it is not difficult to understand. You will recall that your voice is sampled 8000 times a second in pulse code modulation. This means, of course, that a period of 1/8000th of a second goes by between the time it is sampled once and the next time it is sampled.

Now, although 1/8000th of a second is a very short time for human beings, for modern electronic systems it is quite a long time. In that time, in a basic PCM system, it is possible not only to sample your voice and transmit a binary number representing that sample, but also to transmit another **31** binary numbers before the system needs to come back again and sample your voice. This means that the binary numbers representing samples of your speech can be interleaved with 31 others. Two of these numbers carry special signalling information, but the rest can be used to carry telephone conversations. So, including your own conversation, one telephone line can be used to carry 30 conversations simultaneously.

Imagine 30 people all talking on the phone at the same time, with the electronic system going around to them each in turn, taking a sample of their speech and sending it on. At the receiving end, the interleaved binary numbers are analysed each in turn, the different voices reconstructed and sent to 30 different listeners, all without ever mixing up the conversations!

The benefits of digital transmission in the telephone system are many, increasing the quality of telephone calls, and reducing the need to increase the number of wires running between exchanges. Pulse code modulation will become an increasing part of Australia's telephone system.

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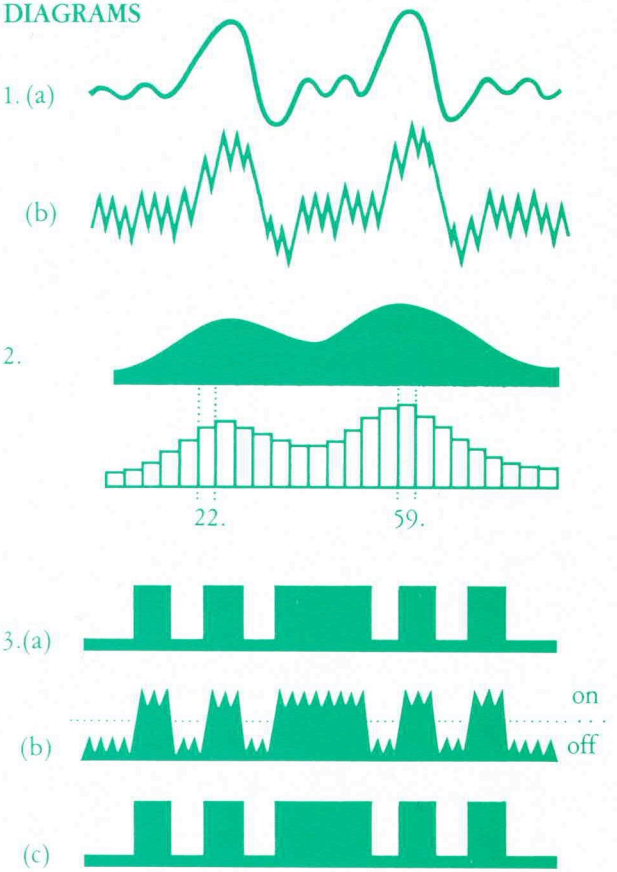
DIAGRAMS



6. DATA COMMUNICATIONS AND PACKET SWITCHING.

A few decades ago, almost all the communications going on over Australia's telephone network were between people. Today, however, a growing part of our everyday telecommunications traffic is not between two people at all, but between a person and a computer, or between two computers alone. By 1982, over 56,000 services were operating in Australia which allowed computers to communicate over the Telecom network; and demand is growing strongly.

There are many reasons why computers need to communicate, or why we as people need to communicate with computers. A growing number of service organisations such as banks, airlines, betting agencies, health insurance companies, and social security departments have small district offices which need to transfer information rapidly to and from their headquarters.

The most familiar example of this, perhaps, is booking an airline ticket: an outlying agency can quickly call up information from the central computer on the number of seats filled on a particular flight, allocate a seat, then immediately inform the central computer that this seat is now taken. All of this can take place in seconds, even though the central computer might be hundreds–even thousands–of kilometres from the district office. In fact, computer communication now takes place internationally as a matter of course.

Many other organisations use such computer communications for internal purposes only, transferring information from one point within the organisation to another for a variety of purposes. It is often economic and reasonable for a large computer to be located centrally, and the various users to be distributed widely depending on the nature of their work, but able to use the computer (through what is called a 'terminal') just as though they were in the same room as the machine. Such users might include computer programmers, word processing operators, librarians seeking information, or technicians entering measurements.

Computers communicate with other computers regularly, too, transferring information from the memory of one into the other, or controlling processes going on at a distant plant; all under instruction, of course. Indeed many of the applications we have discussed so far involve smaller computers communicating with a central computer, or computers in one country communicating with those of another.

A special word, 'data' is often used for the information stored and transferred between computers. So we speak of 'data communication' and 'data processing', which is what computers do.

It is important to realise that data stored in a computer can represent not only numbers, but also letters, symbols and even instructions to the computer. All of this data is stored in a coded form as binary numbers, but we may decode this information in different ways depending on its context. So the same binary number might represent the decimal number '65', the letter 'A', or an instruction to tell the computer to add two other numbers together. The fact that we can code the alphabet into numbers means that words and other text can be stored in a computer. The whole of the text on this page, for example, could be stored in a small amount of computer memory, and transferred from one computer to another in a very small interval of time.

Another word used very frequently in talking about data communication is 'bit'. This is short for 'binary digit', but it is also derived from the idea of a 'small piece' of information. It is the basic unit of information, a binary '1' or '0', a 'yes' or a 'no', an 'on' or an 'off'. The speed of communication of data is usually measured in bits per second (bit/s).

At present, a lot of computer communication goes on over lines which are in effect telephone lines, the same kind of connection that is used for ordinary conversations. Indeed, some communicating computers use dual-purpose connections that are also used for conversation. However in most cases data communication is over privately leased lines which are not switched like ordinary telephone lines at an exchange. Nevertheless, the method of communication still utilises lines and equipment designed for telephony, using analogue transmission techniques.

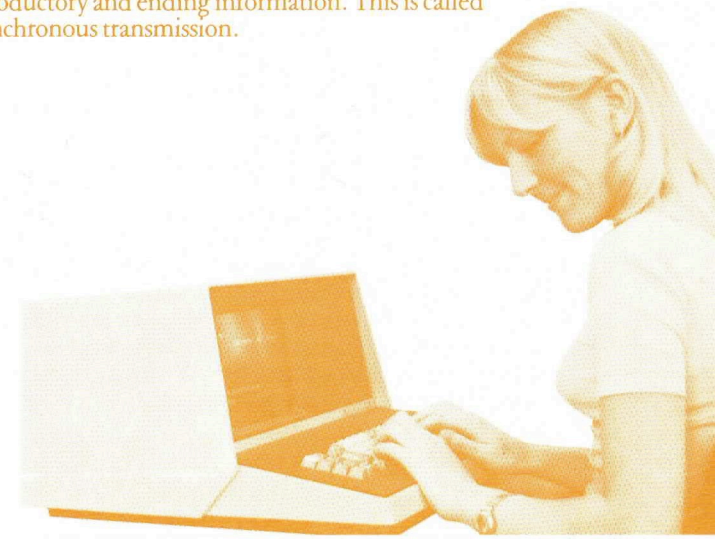
To convert the signals coming out of a computer into a form suitable for transmission at the frequencies of ordinary speech, a device called a data modem is used. 'Modem' stands for **mo**dulator and **dem**odulator. A modem performs a digital to analogue conversion, and transmits the information as a varying tone of sound. There are various ways in which this can be done, and different methods of modulation are used for different speeds of transmission, but the details are too technical to go into here.

The voice frequency tone is then converted by the data modem at the receiving end back into a form that a computer or its terminal can handle. This is called an analogue to digital conversion.

Using such methods, speeds of transmission of up to 9600 bits/s are possible, using ordinary telephone lines. At this speed, all of the words you have read so far on this sheet could be transmitted in just over four seconds.

Now, there is a fundamental difference between the way that people are able to communicate with computers and the way in which computers can communicate with each other. Usually, when a computer is sending information to another computer, it does this by sending one long burst of data. At the beginning of this burst of data would be introductory information which alerted the receiving computer to the fact that information of a certain kind was coming in, and at the end would be information indicating that it was the end. The data in between would all be transmitted at a constant rate without any breaks. This is known as synchronous transmission, and is usually at speeds of 2400 bits per second or greater.

However, when a human being sits down to communicate with a computer, say via a terminal with a keyboard like a typewriter, he or she cannot enter information at anywhere near the speeds that computers can. To a computer, the time between a human hitting one key of a typewriter and the next is almost an eternity. So the information has to be passed down the line one character at a time, as each key is hit. The time until the next character is not predictable: the operator might pause and scratch his nose before going on, for example! So each piece of data must have its own introductory and ending information. This is called asynchronous transmission.



You may be asking, especially if you have read the separate sheet on the benefits of digital transmission, why the digital signals from the computer are converted into analogue signals before transmission. The reason is simple: when computer communications began to become important, the only telecommunications network in existence was the ordinary telephone network, which used exclusively analogue transmission methods. Therefore, in order to make use of this very widespread network, computer information had to be adapted to analogue transmission.

However, digital techniques are now being introduced into ordinary telephony, and the refinement of such digital techniques means that it is feasible for a digital data network to be established especially for computer communications. (See separate sheet on Telecom's plans and developments.) This means that data can travel from one computer to another along transmission lines entirely in digital form, without being converted into voice frequency analogue signals.

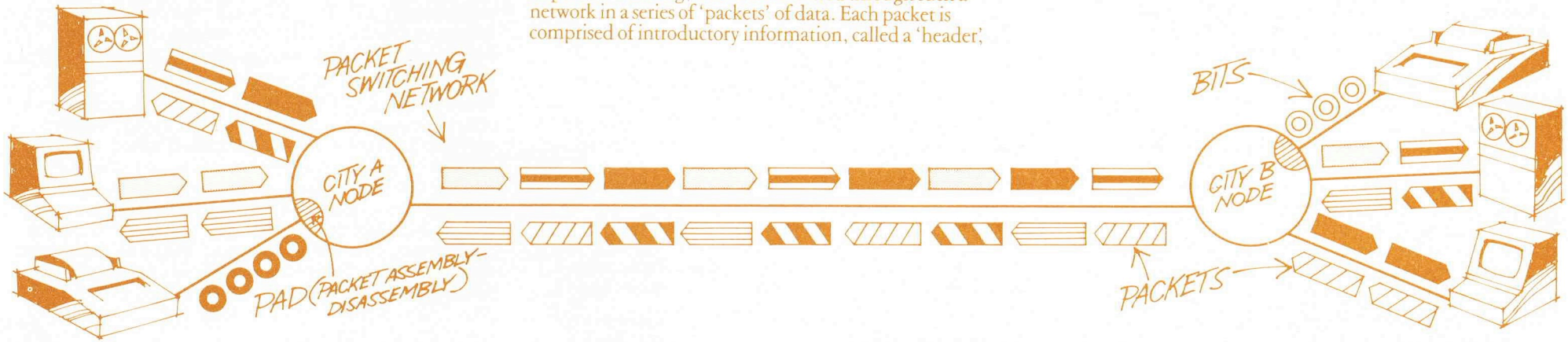
In data communications using the telephone network, the same thing occurs; while communications go on, two or more lines are physically connected together, and remain that way. Those lines are then used exclusively by the transmitting and receiving devices.

However, digital switching involves different principles. You will recall from when we talked about synchronous transmission that the data sent by computers is usually in 'bursts' and between bursts the line is not used. In a packet switching network this principle is used to share physical circuits between many simultaneous users. Switching is done using the logical control of computers. A so-called 'digital switch' does not consist of a physical electro-mechanical switch to connect two lines together, but rather a set of instructions to a computer which tell it to pick up and re-route pieces of data as they come in, automatically checking them for errors, and sending them on to their correct destinations.

In packet switching, data is transmitted through such a network in a series of 'packets' of data. Each packet is comprised of introductory information, called a 'header,

Within the packet switching network, data can travel at speeds of 48,000 bits per second. At this rate, the entire English Bible, some 770,000 words, could be transmitted in under fourteen minutes! One of the strongest benefits of such a network, however, is that different kinds of communicating devices can communicate with the network at their own rate either synchronously or asynchronously. Only once the data has reached a packet switching 'node'–the equivalent of an exchange–is it transmitted at the rapid 48,000 bit/s rate. Asynchronous data ('one character at a time' from a terminal operated by a human) is converted at the node into data packets by a packet assembly/disassembly facility. The same facility converts packets of data into a form suitable to send to an asynchronous device.

Within the network, packets of data moving along a particular line are mixed in with packets from many different sources. They contain enough information to enable them to be simply sorted out again at the receiving



A further development in data communications has been introduced into Australia recently. This involves the concept of packet switching. To understand what this is about, we first have to recall what we know about switching in the telephone network. When you dial a telephone number, the traditional kind of telephone exchange operates an electromechanical switch to connect you with a line going to the telephone of the person you wish to speak to. This might involve switching your line to a line going to a series of other exchanges, but in any case, when the call is put through, there is a physical connection between your telephone and the telephone of the person you are speaking to, which lasts for the duration of the call.

which contains information about the destination, source, and type of the communicating mechanisms; the data being transmitted, up to a maximum of 1024 bits; and a tail which contains an error-checking code, to confirm that no mistakes have been made in sending the data. If an error is detected, at any link of the network, the last link is instructed to retransmit the packet. This improves the overall accuracy of the system enormously.

The term 'packet' is really quite appropriate. The packet switching network operates rather like Australia Post handling parcels; each parcel has its own address label, and this is read and used to direct the parcel to its correct destination.

end, and the right ones sent to the right destination. This means that the network can be used very efficiently, as the same transmission line does not need to be kept open between two devices whether or not they are transmitting.

Introduced at the end of 1982, packet switching is the most sophisticated method of data communication ever used in Australia.

Telecom Australia

7. TELECOM'S PLANS AND DEVELOPMENTS IN DIGITAL TRANSMISSION AND DATA COMMUNICATION.

Pulse Code Modulation

Pulse code modulation (PCM) is a method of transmitting information (the human voice, computer data) by digital methods, increasing the capacity of lines and reducing the effect of noise. The use of these methods within Australia's telecommunications network is now increasing dramatically.

The first 30-channel pulse code modulation systems in Australia were installed in Queensland in October 1978, and by mid-1983, about 1000 total PCM systems had been installed. Most of these systems have been installed in Brisbane and Melbourne so far, where their ability to carry many more telephone conversations per pair of wires has helped relieve severe overcrowding in cable ducts between city telephone exchanges.

It is expected that during the 1980s, the number of PCM systems in Australia will grow significantly, with major increases occurring in Sydney. Approximately 2000 systems are likely to have been installed by 1984, not only on cable installations, but also on optical fibre and microwave radio systems.

The increasing number of digital transmission systems in the Australian telecommunications network will form the basis of the digital data network for computer communications, described in more detail later.

In the longer term electronic telephones will be available which will perform analogue to digital and digital to analogue conversions within the instrument itself, and so enable digital transmission between the subscriber and the exchange.

Electronic and Digital Switching

Electronic control of telephone exchange equipment was introduced into Australia in 1960, when the first 'crossbar' exchange was opened in Queensland. Crossbar equipment, though employing traditional electromechanical technology, offered space savings and increased reliability because there was common control of the switching. This means that instead of having to duplicate the control mechanisms for each piece of switching equipment, as in older exchanges, electronic equipment supervises the switching, and connects circuits as they are needed. Crossbar is used extensively in the Australian network, and is now being brought up to date with the addition of equipment called ARE-11, to bring it into the modern era of computer control.

The next stage is fully electronic switching. This means that instead of using mechanical devices controlled by electromagnetic means, control of the system is performed by specialised computers, following instructions stored in their memories. These instructions, or programs, control all switching operations, normal maintenance tests, and access to the system.

Australia has adopted the Swedish AXE system for this new generation of telephone switching, and the first such exchange was installed at Endeavour Hills, a suburb of Melbourne, in 1981. AXE is being progressively installed in other capital cities, and by 1985, some 270,000 lines should be operating on the new system.

An important decision regarding this equipment was made during 1981, when it was decided that all AXE exchanges after the first should incorporate entirely digital switching methods. This means that no electromechanical switching devices would be used at all, so that all calls will be connected and routed electronically by means of logical computer control, without the use of moving parts (for more details on digital switching, see Telecom Information Kit #3, "The Switching Place").

This introduction of digital switching means that PCM systems, employing digital transmission, can more easily be interfaced with the exchange. It will mean that the existing telephone network can move towards a fully digital system in both transmission and switching to form an Integrated

Digital Network (IDN). Obviously, this will take a long time, as our present system is so extensive, and still almost entirely based on electromechanical and analogue technology. But the IDN is a goal which will be progressively reached as we move towards the 21st century.

Datel Services

Telecom's Datel Services, which enable people to communicate with computers, or computers to communicate with each other over the existing telecommunications network, have been available since 1969, when they were introduced by the then Australian Post Office.

Since the telecommunications system has until very recently employed purely analogue transmission methods, a Datel service involves converting the digital data from a computer or terminal into an analogue audio signal suitable for transmission along ordinary telephone lines.

Transmission may be over the ordinary switched telephone network, or along privately leased lines; the advantage of the latter services is that the connection is permanently wired and not switched and can provide a higher quality connection. A speed of 48,000 bits per second is possible using special high speed data lines. Over the switched network, transmission speeds can be 300, 600, 1200, 2400 or 4800 bits per second.

Datel services require a data modem, supplied by Telecom, at each end of the line to convert the digital data from the computer into an analogue form suitable for transmission along telephone lines and back again into digital form at the receiving end.

Telecom also now offers an analogue data service for the increasing numbers of equipment which include their own modems. In this case, Telecom supplies the line only.

The Digital Data Network

At the end of 1982, Telecom introduced a digital network specifically designed to carry data communications, in contrast to the existing telecommunications system which is essentially a medium for voice communications, adapted in various ways to carry data, telex and broadcast links.

The Digital Data Network provides faster connection times and much more secure links for computer communications. It uses digital transmission methods similar to those of PCM systems.

The pilot network commenced operation in September 1981 between Melbourne, Canberra and Sydney, and full nation-wide operation of the network began at the end of 1982.

The basic service offered by the digital data network is similar to that of the leased line Datel service, providing transmission speeds of 2400, 4800, 9600, and 48,000 bits per second. It also provides major new facilities which benefit users with large networks to computers and terminals.

Costs to use the new services are less than for the equivalent Datel service, especially for long-distance computer communications.

Packet Switching

Coinciding with the introduction of the digital data network, Telecom has also established a packet switched data service, known as 'Austpac'. Packet switching involves the routing of data in discrete quantities called packets, each with its own address and control information. The movement of these packets is controlled by supervisory computers, and they travel on a high capacity, high speed data link.

Austpac accepts data fed to it at a variety of transmission speeds, and automatically converts that data back to the appropriate speed for the receiving device, in either asynchronous or synchronous format as necessary. It offers increased efficiency and greatly increased error checking.

Austpac began operating at the end of December 1982.

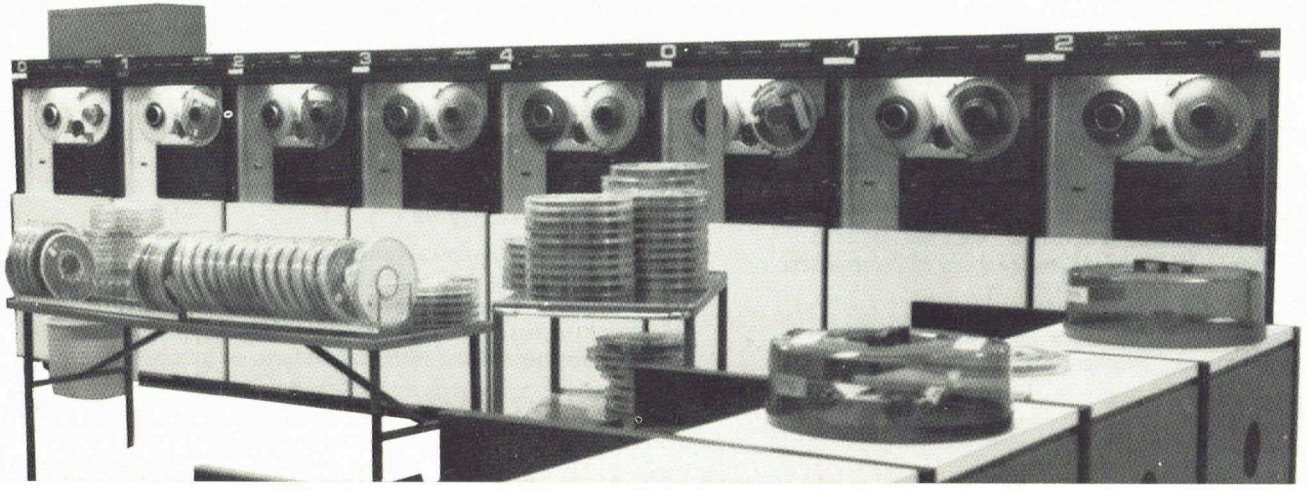
The Integrated Services Digital Network

With the increasing use of digital transmission and digital switching methods in the telephone network, and with the growth of data communications, it is possible to envisage Australia's telecommunications network reaching a stage where all communications on it would be carried by digital means.

At this stage, it would probably no longer be necessary to make a sharp distinction between voice communications between people, data communications between computers, and other communications means like telex, facsimile or videotex. All services would be carried by digital methods, transmitted in the form of binary numbers using pulse code modulation.

When this stage arrives, all these different services might be integrated together, carried on a common system. This would be the Integrated Services Digital Network. Such a network is still a long way from implementation, barely yet more than an idea. Yet it is an idea whose time seems certain to come.

In such an integrated network, digital pulses would be flooding at an incredible rate from one end of the nation to the other, ceaselessly. Even if you could examine a small segment of that digital stream, there would be no way you could tell whether it represented a sample of a conversation between two friends; information for an airline booking; part of a photograph being sent by facsimile; part of a videotex display of the latest stock market figures; or data being sent from one computer to another. Indeed, the data stream would probably contain all of these things simultaneously.



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6. Data Communications and Packet Switching.
7. Telecom's Plans and Developments in Digital Transmission and Data Communication.

FROM DOTS TO DATA

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